Science Applications of the Geodetic VLBI

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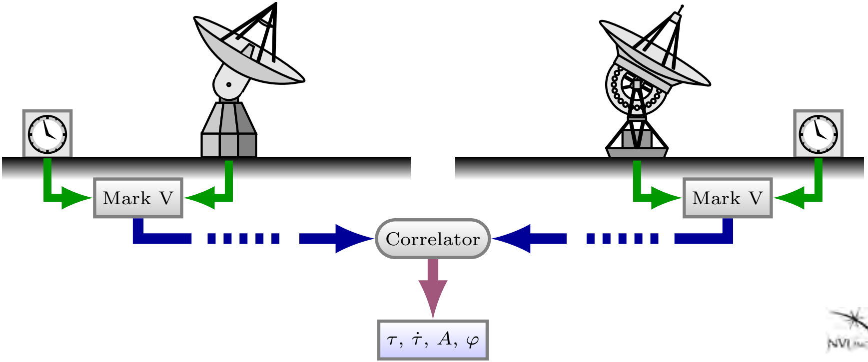
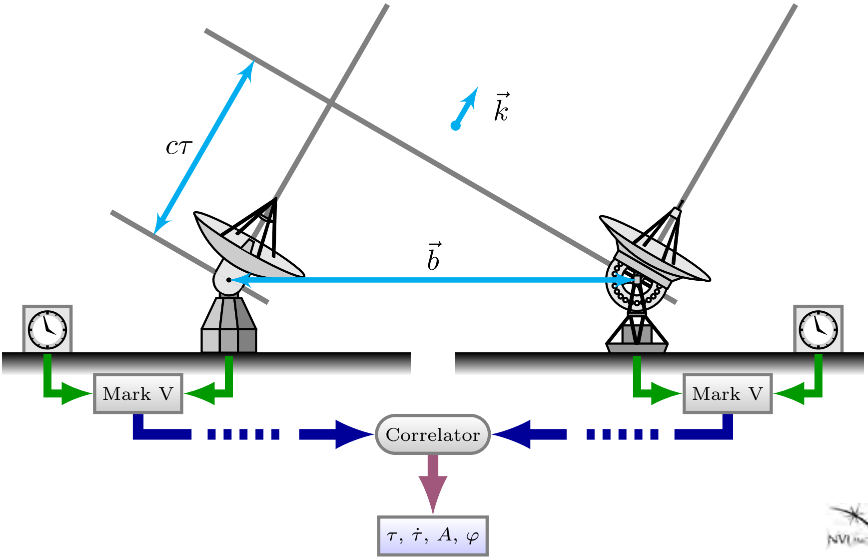
VLBI observations

VLBI observations



VLBI observations



VLBI: "observable" quantities

The following values we considering as observable:

- Time delay τ
- Delay rate $\dot{\tau}$
- Amplitude A of visibility function
- Phase φ of visibility function

$$\tau = -\frac{1}{c}\vec{k} \cdot Q(t) \cdot \vec{b} + \tau_c + \tau_{ion} + \tau_{atm}$$

where Q(t) is a matrix of transformation from Terrestrial to Celestial reference frame;
τ_c is a clock offsets and delay of signal propagation at stations;
τ_{ion} taking into account ionosphere;
τ_{atm} is a delay caused by troposphere.

Tasks

VLBI

VLBI: VLBI is an unique method of space geodesy, that allows to construct Celestial Reference Frame (CRF), Terrestrial Reference Frame (TRF) and determine the mutual orientation of these frames.

The primary parameters that are estimated in VLBI data analysis:

- Coordinates and velocity of the observing stations.
- Positions of radio sources.
- Earth orientation parameters (EOP): (p_x, p_y), $d(UT1 - UTC)$, $(dX, dY)_{CIP}$
- Parameters of troposphere in a place of observation.

Geodetic VLBI Tasks:

- Construction and maintaining the reference frames.
- Studies of the tectonic plate motion.
- Investigations of the free rotation modes of Earth.
- Adjustments of various parameters that describe Earth internal model.
- Monitoring of the ionosphere and troposphere.
- Testing of the General relativity theory
- Building maps of source brightness distribution.

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International VLBI Service

International VLBI Service for Geodesy & Astrometry (IVS)

HTTP://IVSCC.GSFC.NASA.GOV

The Service has been established in 1999.

Main components: observing stations, correlators, coordinating centers, data centers, data analysis centers.
IVS coordinates activities of **43** agencies from **20** countries.

Primary goals of IVS:

- to provide a service to support geodetic, geophysical, and astrometric research and operational activities;
- to promote research and development activities in all aspects of the geodetic and astrometric VLBI technique;
- to interact with the community of users of VLBI products and to integrate VLBI into a global Earth observing system.

Data and products of IVS:

- VLBI observations;
- solutions of TRF and CRF;
- time series of the EOP;
- time series of the tropospheric parameters.

Components of the IVS

Map of distribution of IVS components

Geodetic VLBI: equipment

VLBI stations

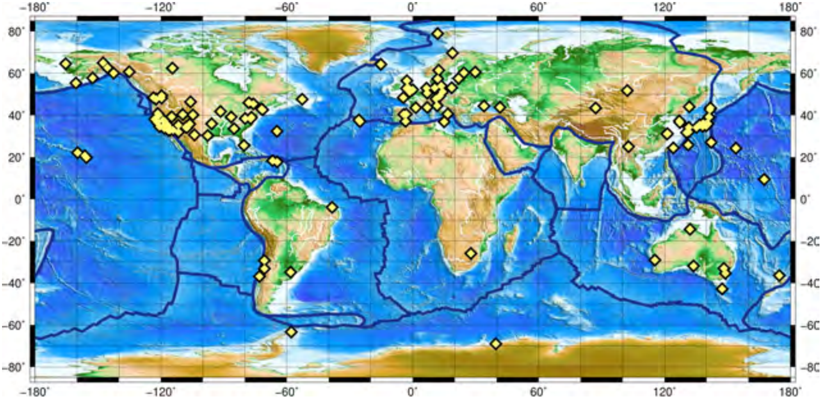


Figure: All available (current and historical) VLBI sites.

Implementation of the International Celestial Reference System

International Celestial Reference System (ICRS)

ICRS is the current standard celestial reference system adopted by the International Astronomical Union (IAU). Its origin is at the barycenter of the Solar System, with axes that are intended to be "fixed" with respect to space.

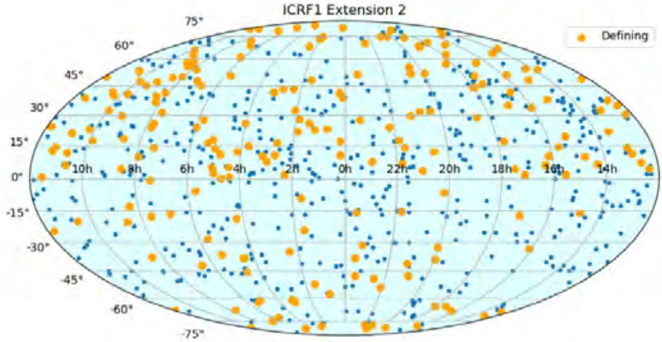
International Celestial Reference Frame (ICRF)

ICRF is a realization of the ICRS using reference celestial sources. It is a set of coordinates of the reference objects derived from observations.

Realizations of the ICRF

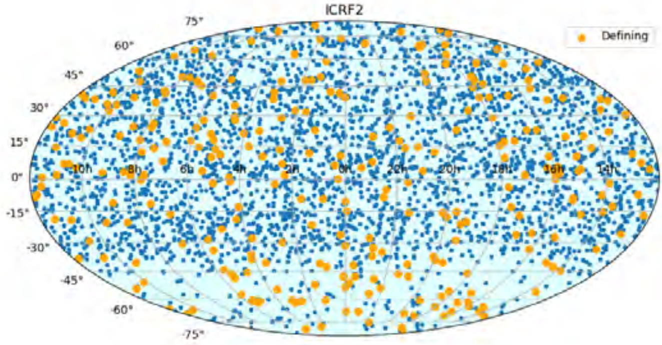
- Catalogs of stars obtained from optical observations. The latest is FK5 (1991).
- ICRF1 (1998), ICRF1-Ext.1 (2002) and ICRF1-Ext.2 (2004).
- ICRF2 (2009).
- ICRF3 (2019).

ICRF1-Ext.2



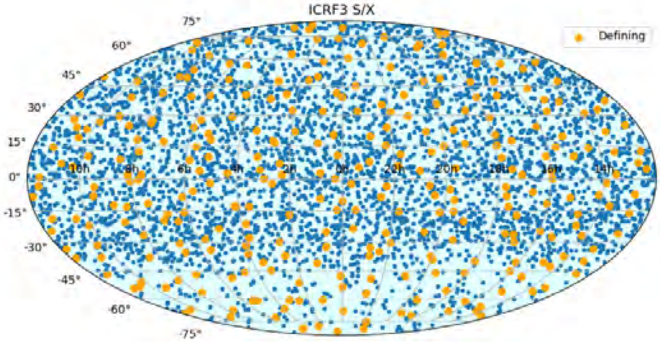
Based on 1.6M S/X VLBI observations.
Contains coordinates of 717 radio sources.
212 defining objects.
Noise floor: $250 \mu as$
Axis stability: $20 \mu as$

ICRF2



Based on 6.5M S/X VLBI observations.
Contains coordinates of 3414 radio sources.
295 defining objects.
Noise floor: $50\mu as$
Axis stability: $10\mu as$

ICRF3



Based on 15M S/X, plus X/Ka and K VLBI observations.
Contains coordinates of 4536(S/X), 678(X/Ka), 824(K) radio sources.
303 defining objects.
Noise floor: 20-30μas
Axis stability: $<10\mu as$

Implementation of the International Terrestrial Reference System

International Terrestrial Reference System (ITRS)

ITRS defines a geocentric Earth fixed system of coordinates using the SI system of measurement.

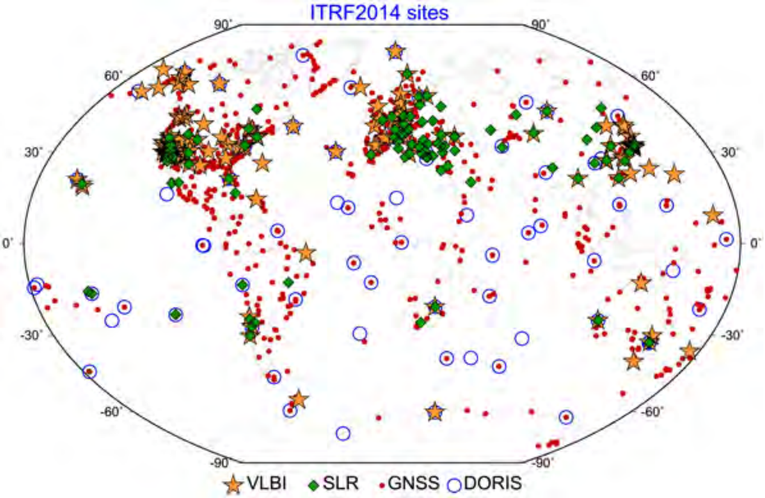
International Terrestrial Reference Frame (ITRF)

ITRF is a realization of the ITRS using coordinates and velocities of a set of stations observed with space geodesy technique.

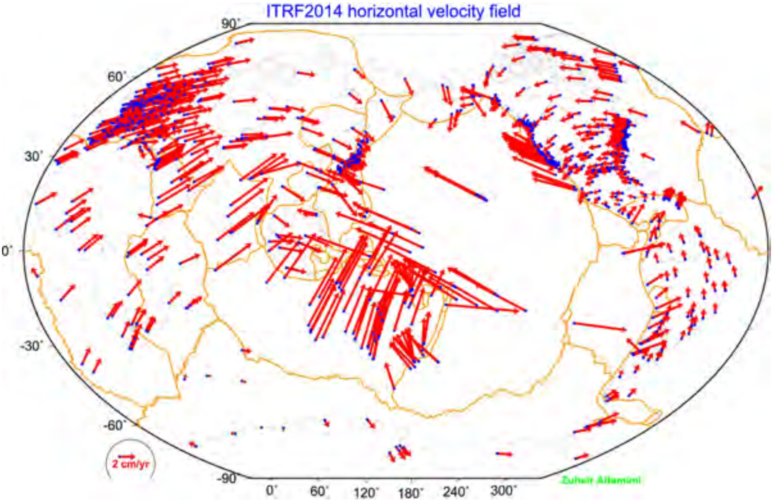
Releases of the ITRF

- First realization of the ITRF was in 1992.
- The releases are made every several years.
- Methods of combination of the VLBI, LLR, GPS, SLR, and DORIS observations into one common solution improves with every release.
- The latest ITRF release was made in 2014 (204 VLBI stations).

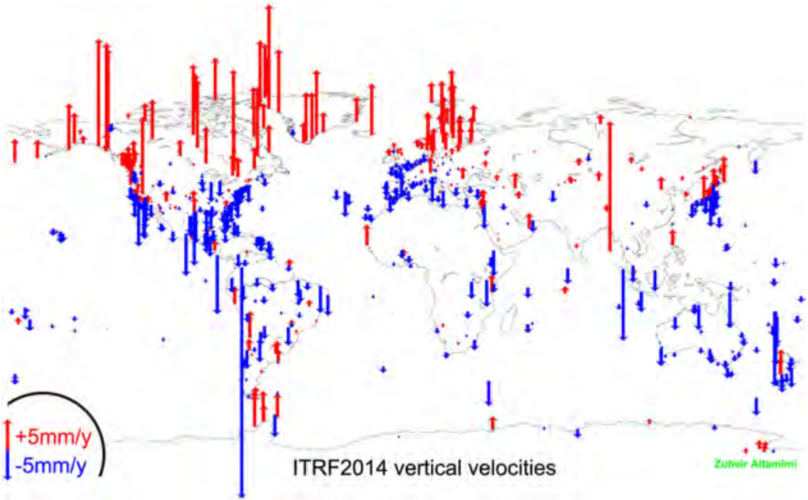
ITRF2014


ITRF2014 sites
90°
90°
60°
60°
30°
30°
0°
0°
-30°
-30°
-60°
-60°
-90
-90°
VLBI
SLR
GNSS
DORIS

ITRF2014


ITRF2014 horizontal velocity field
90°
60°
30°
0°
-30°
-60°
-90
0°
60°
120°
180°
240°
300°
2 cm/yr
Zuheir Altamimi

ITRF2014



Connecting Celestial and Terrestrial reference frames

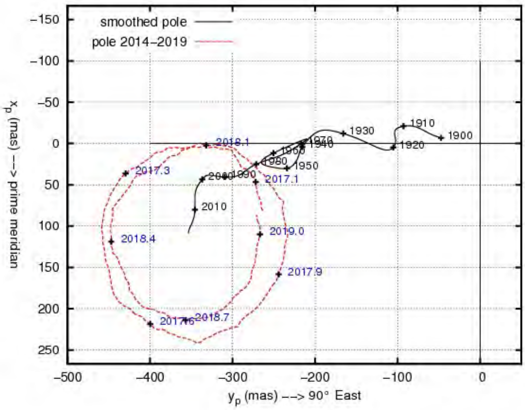
Transformation between TRF and CRF

- Earth (and associated with it the Terrestrial reference frame) rotates with respect to the inertial reference frame.
- Earth rotation is a complex motion, a combination of forced and induced free oscillations. Theory of Precession-Nutation predicts the position of Earth axis of rotation in the inertial space as a function of time.

Earth orientation parameters

- Polar motion, p_x and p_y.
- Changes in Earth rotation, d(UT1-UTC).
- Nutation angles: the Celestial pole offset, dX and dY.

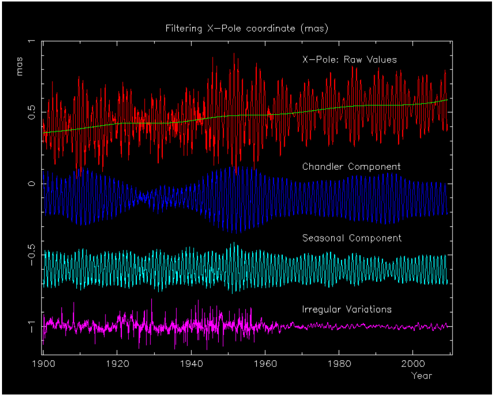
Polar motion



Polar motion

The motion of the rotation axis of the Earth relative to the crust.

Polar motion



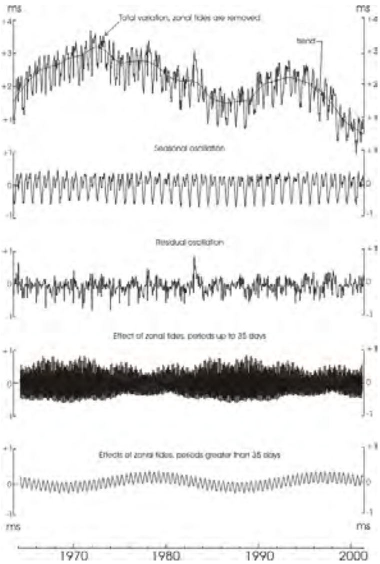
Polar motion, x-component

Polar motion is the movement of the point where the Earth's rotational axis intersects the crust.

The polar motion has major components:

- Secular drift;
- A free oscillation of 430 days, Chandler Wobble;
- An annual oscillation caused by ocean and atmosphere.

Irregularities of Earth rotational velocity



- Variations of Earth angular velocity expressed either as d(UT1-UTC) or as change of length of day, ΔLOD.
- Both values are related as follows:

$$\Delta LOD = -\frac{d(UT1 - UTC)}{dt}$$

- Change of Earth rotation is caused by various factors: solid Earth tides, ocean tides, seasonal oscillations in atmosphere.
- UT1 is the most critical EOP parameter, since it changes the most rapidly. VLBI is the only technique that precisely measures UT1.

High frequency variations in Polar motion and Earth rotation

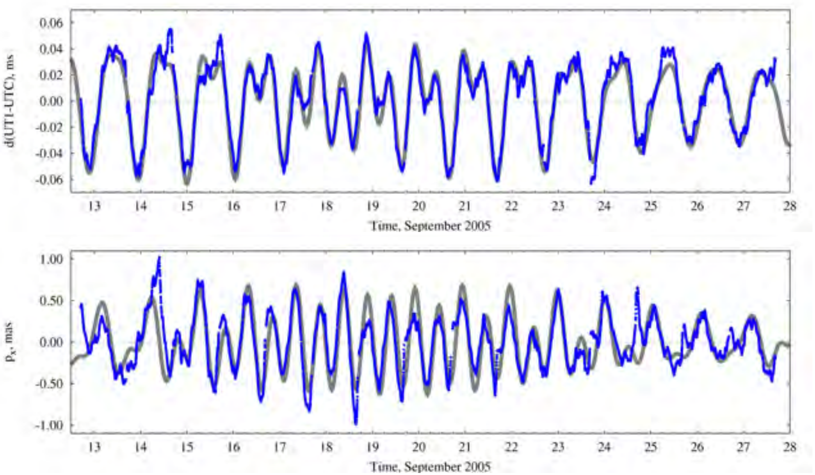
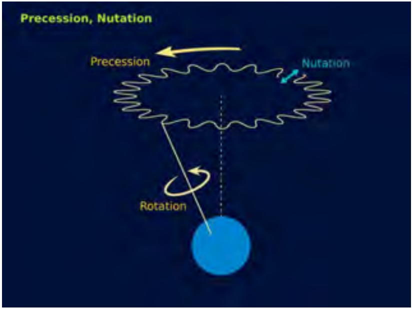


Figure: Estimations with high time resolution of the polar motion and d(UT1-UTC) from CONT-05 VLBI campaign. Comparison with theoretical model of diurnal and semi diurnal tidal variations (Ray, 1994).

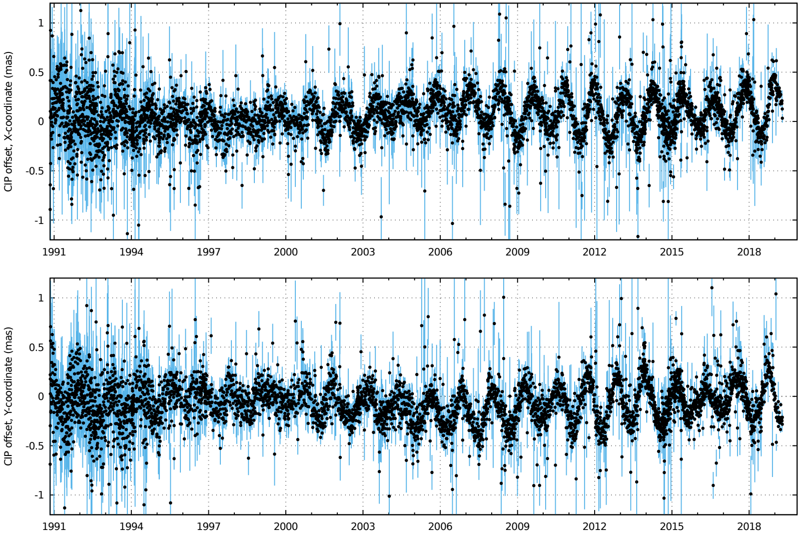
Celestial pole offset



Earth rotation axis in the inertial space

- Orientation of the Earth rotation axis in the CRF is modeled by theory of Precession-Nutation.
- Corrections to the Precession-Nutation model, the Celestial Pole offset (dX and dY), are the two parameters that are adjusted from observations.
- The Celestial Pole offset can be obtained only from VLBI technique.

Estimations of the CIP offset from VLBI observations



Estimation of the zenith delays

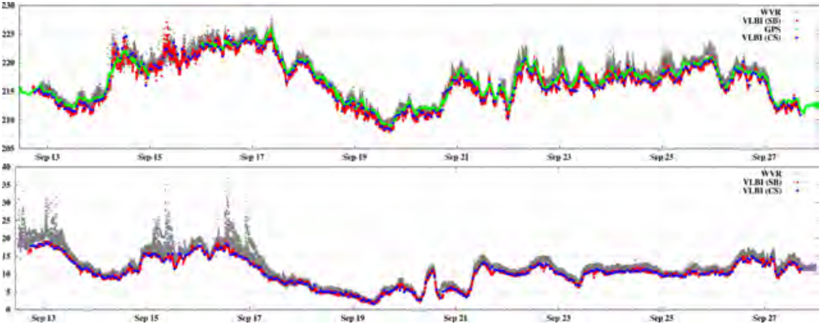


Figure: Estimation of the zenith delays at KOKEE (top) and WETTZELL (bottom) stations from CONT05 VLBI campaign. Comparisons with WVR (gray) measurements and the estimations from GPS observations.

Summary

Importance of VLBI technique

- VLBI is the unique technique that is capable to connect Terrestrial and Celestial reference frames.
- Only from VLBI data analysis it is possible to constructs ICRF, VLBI also provides significant contribution to ITRF.
- VLBI is an important contributor to many areas of science.
- The next generation of VLBI stations will provide even better results.

Acknowledgment

All these results would be impossible without efforts of many people at stations.

THANK YOU VERY MUCH!

In this presentation materials from the following organizations were used: IVS, IGS, IERS, IGN, Observatorie de Paris and BKG.